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DEPARTMENT OF INTERNAL AFFAIRS

GROUND WATER FOR AIR CONDITIONING AT PITTSBURGH, PENNSYLVANIA

By

D. W. Van Tuyl

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By

D. W. VAN TUYL

U. S. Geological Survey

Supplement to Bulletin W 8

Ground-water Resources of the Valley-fill Deposits

of

Allegheny County, Pa.

Prepared cooperatively by

UNITED STATES GEOLOGICAL SURVEY

DEPARTMENT OF INTERNAL AFFAIRS

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CONTENTS

ILLUSTRATIONS

TABLES

GROUND WATER FOR AIR CONDITIONING AT PITTSBURGH, PENNSYLVANIA[1]

BY

D. W. VAN TUYL[2]

ABSTRACT

This report describes the use of ground water specifically for air-conditioning purposes in the Triangle area of Pittsburgh, showing the rapid increase in pumping for this use since 1930. It covers in detail the history of wells and ground-water pumping and outlines the factors affecting the availability of the ground water. The report supplements the earlier "Ground-water resources of the valley-fill deposits of Allegheny County, Pa.," by including current records of water levels, water temperatures, chemical quality, and pumping rates.

The growth of air conditioning is reflected in the steady increase in the use of ground water for cooling, which originated in 1927 and amounted to about 500 million gallons in 1950. During this same period, the pumpage for all uses in the Triangle area about doubled, from 1,300 million gallons in 1930 to about 2,500 million in 1949. The pumpage for air conditioning in 1950 was about 25 per cent of the total pumpage for all uses, whereas in 1940 it amounted to only 10 per cent of the total. On a daily-rate basis during the average air-conditioning season, which is taken as 100 to 120 days, the ratio of air-conditioning use to total use was about 25 per cent in 1940 and 50 per cent in 1950.

Records of water temperature since 1937 are presented in graphical form, comparing ground water during the air-conditioning period of each year to Allegheny River water. The maximum and minimum temperatures of the ground water lag behind the corresponding values for the river water by as much as 4 or 5 months. The ground water generally is colder than river water throughout the normal air-conditioning season. River temperatures range from 34° F. to the mid-80's, while well-water temperatures range from 48° to 73°. No definite trend is apparent in the temperature records of either ground water or surface water.

The chemical quality of the ground water, as shown in five recent analyses, appears to be suitable for its use in air conditioning and most other purposes.

The future of the Triangle area as an area of ground-water development is good, although little if any development beyond present amounts would seem to be advisable. This conclusion is based on contour maps of the water table at its approximate highest and lowest positions. The drawdown of water level by heavy summertime pumping extends over most of the Triangle area, amounting to 8 or 10 feet in some observation wells. Drawdown is limited by the relative thinness of the water-bearing formation, and recharge is limited by both natural and man-made barriers.

Several methods of conserving the ground-water supply are outlined in the report, including the advantages and disadvantages of artificial recharge through return wells. Voluntary waste control is proposed as a promising method of preserving the usefulness and yield of the aquifer.

The report is intended as an outline of the ground-water conditions in the Triangle area, to serve as a guide in the future use and development of ground water for air conditioning and other uses.

[1] Publication authorized by the Director, U. S. Geological Survey.

[2] Hydraulic Engineer, U. S. Geological Survey.

INTRODUCTION

PURPOSE AND SCOPE OF REPORT

This is the tenth of a series of reports which present the results of continuing ground-water investigations throughout Pennsylvania. The investigations were started in 1925 by the U. S. Geological Survey in cooperation with the Pennsylvania Topographic and Geologic Survey. The reports have been published by the State agency as a series of ground-water bulletins whose serial numbers are preceded by the letter W.

This report supplements Bulletin W 8, which is an inventory of ground-water data in Allegheny County (Adamson, Klein, and Graham, 1949).[3] Additional data have been collected in the Pittsburgh area since that report was prepared, and a detailed analysis has been made of ground-water pumping in the Triangle area—the downtown business section of Pittsburgh. A history of pumping has been compiled for the 21-year period 1930-50, the use of water being classified as for air conditioning or for all other purposes. The records of ground-water levels presented in Bulletin W 8 have gained in length, and new maxima and minima of record were observed in many observation wells in 1949 and 1950. These extended records are shown in this report, and the causes of the major fluctuations are discussed. In addition, the surface of the water table in the Triangle area has been contour-mapped for the first time, showing the nature and extent of the regional cone of depression caused by the concentrated pumping in the area. In this report, also, new and current chemical analyses of the ground water are given, and detailed temperature data are shown.

The main purpose of this report is to assemble and present in usable form all the pertinent data regarding the use of ground water in air conditioning and the factors affecting the future availability of the supply in this area. These data should be made known to and used by well owners, well drillers, equipment concerns, and consultants in planning ground-water developments in the Triangle area. Otherwise, installation for air conditioning and other purposes may be short-lived or improperly designed for the conditions existing in the underground reservoir.

The area under consideration in this report is known as the Golden Triangle of Pittsburgh, comprising 0.4 square mile at the confluence of the Allegheny and Monongahela Rivers. Included in the report are maps that show the configuration of the underlying bedrock surface and the water table by contours, and by symbols the locations of wells and their use classification. Pumpage by individual users for air conditioning and for other purposes is tabulated. Fluctuations of water levels and water temperatures are shown in graphs, and chemical analyses are given for five locations. A final section dealing with conservation explains some of the readily available methods which could be applied in this area to continue the useful life of the water-bearing deposits.

This study was made under the general supervision of A. N. Sayre, Chief, Ground Water Branch, U. S. Geological Survey. The cooperative ground-water program in Pennsylvania is under the immediate supervision of J. B. Graham, District Geologist.

[3] See references, p. 33.

ADVANTAGES OF GROUND WATER

In general, ground water is preferred to surface water for air conditioning because of the temperature factor. Natural ground water has a nearly constant temperature equal to or slightly above the mean annual air temperature of the region, whereas surface water ranges in temperature from near freezing in winter to 80° or 90° F. in summer. Ground water derived by infiltration from nearby surface sources, as in the Triangle area, fluctuates in temperature above and below the annual mean, but less than does surface water. Thus, during the air-conditioning season, ground water is generally cooler than adjacent river water, giving it an advantage for use in cooling.

Another advantage of ground water is its fairly constant chemical quality, as compared to the variable quality of surface water. Although generally harder, ground water contains no suspended matter and rarely requires treatment or sterilization prior to use.

The availability of ground water at specific sites generally results in costs of development, operation, and maintenance that are lower than the cost of developing and transporting surface water from the nearest available source.

ACKNOWLEDGMENTS

Initial field work and compilation of records was done by J. H. Adamson, Jr., and N. H. Klein in preparing Bulletin W 8. Most of the subsequent data were assembled by Mr. Klein and the author specifically for this report. The maps of the Triangle area were prepared by the Pennsylvania Topographic and Geologic Survey. Detailed temperature and pumpage data were furnished by the Joseph Horne Co., through the courtesy of W. W. Boyle. Allegheny River temperatures were obtained from the Pittsburgh Filtration Plant, through the courtesy of C. F. Drake. Detailed air-conditioning data were furnished by the Trane Co., through the courtesy of R. M. Toucey. The author thanks these individuals and others who assisted in supplying the data used in the report.

The author acknowledges the valuable advice and criticism by S. H. Cathcart and R. C. Stephenson of the Pennsylvania Topographic and Geologic Survey.

HOW WATER IS USED IN AIR CONDITIONING

TYPES OF SYSTEMS

Air conditioning serves two major uses. The first is air conditioning for comfort, which involves rather narrow ranges of temperature and humidity and the factors of cleanliness and adequate circulation of air. The second is air conditioning for industrial and process purposes, which covers a wide range of temperature and humidity, depending on the job to be done. Most of the air conditioning in the Triangle area of Pittsburgh is of the first, inasmuch as the buildings supplied with conditioned air are occupied mainly by people rather than by industrial machinery and products.

Air-conditioning systems employ either natural cooling ingredients such as water and ice or artificial refrigerants such as Freon, ammonia, carbon

dioxide, and sulfur dioxide. In the former, or natural refrigeration, heat is absorbed in melting the ice or warming the cool water. In the latter, or mechanical refrigeration, heat is absorbed when the liquids are evaporated. Artificial refrigerants are ordinarily used over and over by completing the cycle—compression and condensation of the gas to liquid.

Air-conditioning systems that use only cold water for cooling are relatively simple in design, but they require water generally below 55° F. and in large quantities at reasonable cost. Among these are the common air washers and certain combination systems containing direct-expansion coils or shell-and-tube coolers. Systems that use liquid refrigerants may also use water, in a number of ways:

1. Water precools the air after having cooled the coils of the condenser through which the refrigerant passes.
2. Water subcools the liquid refrigerant leaving the condenser.
3. Water is sprayed on the condenser coils across which air is drawn—the evaporative condenser.
4. Water cooled by artificial refrigeration is circulated in tubes and cools air drawn across the tube.

Only in the last of these four methods is the cold water itself used for actually conditioning the air. One advantage of this method is that chilled water can be easily circulated to air-conditioning units in many locations throughout a plant or office building. Water is needed in lesser amounts and may be at temperatures above 55° in each of the first three methods.

In summary, then, air conditioning that employs only water as the cooling agent requires more water than air-conditioning systems using liquid refrigerants. Water requirements for systems using liquid refrigerants range from very small to amounts as great as those used by the direct water systems, depending on the mechanical design of the refrigeration cycle.

AMOUNTS REQUIRED

The amount of water used in air conditioning depends on the type and size of the system, on the degree of cooling desired, and on the temperature of the water. The size of a system is based on the calculated heat gains in the space to be conditioned. The design of the refrigerating plant is based on the cost of water in relation to the quantity and temperature of water available, and on the occupancy and structural features of the building. Air flow is expressed in cubic feet a minute (cfm) and refrigerating capacity is expressed in tons. Apparatus that removes heat at the rate of 12,000 Btu (British Thermal Units) per hour is said to have a capacity of 1 ton of refrigeration. This expression is derived from the fact that melting 1 ton of ice in 24 hours requires heat at the rate of 12,000 Btu per hour.

The quantities of water required in air conditioning are shown by the data in Table 1. The quantity to be used in any system is determined after calculations have been made for heat gains, amount and condition of the air supply, size of the plant, and other factors.

Table 1. *Quantities of water required for absorbing heat**

Rise of Water Temperature (°F.)	Quantities in Gallons a Minute	
	Per 1,000 Btu per hour	*Per ton of refrigerating capacity*
1	2.0	24.0
2	1.0	12.0
4	.50	6.00
6	.333	4.00
8	.250	3.00
10	.200	2.40
12	.167	2.00
14	.143	1.71
16	.125	1.50
18	.111	1.33
20	.100	1.20

* Trane air conditioning manual (1941), table 7-2, p. 355.

The cooling load varies with the design range of wet-bulb temperatures. According to the American Society of Heating and Ventilating Engineers, the design wet-bulb temperature of outdoor air at Pittsburgh is 78° F. Likewise, the refrigerating capacity varies with the cooling load, based on temperatures, and with the amount of air to be conditioned. The data in Table 2 indicate these variations for systems located at Pittsburgh.

Table 2. *Cooling loads and required refrigerating capacities at Pittsburgh**

Indoor Wet-bulb Temperature (°F.)	Design Range of Temperature (°F.)	Cooling Load (*Btu per hour per cfm air*)	Refrigerating Capacity (*tons per 1,000 cfm air*)
60	15	52.4	4.36
61	14	49.4	4.11
62	13	46.3	3.86
63	12	43.2	3.60
64	11	40.0	3.33
65	10	36.7	3.06
66	9	33.4	2.78
67	8	30.0	2.50
68	7	26.5	2.21
69	6	23.0	1.91

* Trane air conditioning manual (1941), tables 3-20, p. 308, and 5-3, p. 327.

In a hypothetical air-conditioning problem, estimated water quantities could be determined from the data in Tables 1 and 2. With water admitted at 60° and discharged at 72°, find the amount used in conditioning 4,500 cfm of air to a wet-bulb temperature of 65°. Solution: From Table 2, the refrigerating capacity required is 3.06 tons per 1,000 cfm, or 13.8 tons for 4,500 cfm; from Table 1, the quantity of water needed is 2.0 gallons a minute per ton, or 27.6 gallons a minute for this job.

In the air-conditioning industry the solution of problems of this nature is performed graphically through use of the psychrometric chart and the air-conditioning ruler. Furthermore, the problem usually is one of finding

the quantity of air required and the temperature at which it should be supplied in order to maintain a given temperature in a room, which has a certain heat loss.

AVAILABILITY OF GROUND WATER

GEOLOGY OF THE TRIANGLE AREA

The Triangle area is on the edge of an ancient river valley that was eroded into much older consolidated rocks. The configuration of the rock valley beneath the Triangle area is indicated by contours on the bedrock surface in Figure 1. The character and thickness of the valley-fill deposits are shown by the cross section in Figure 2. These illustrations are taken from more complete drawings appearing in Bulletin W 8. During Pleistocene time, large volumes of water flowing down the Allegheny River from melting glaciers to the north carried and deposited large quantities of sand, gravel, clay, and silt which partially fill the old rock valley. Finer-grained sediments from its unglaciated drainage area were laid down by the Monongahela River. Post-glacial stream action has further washed out and sorted these deposits. Recent flooding has also covered them with layers of alluvium consisting in part of silt. The present rivers are flowing over only parts of the preglacial channels, and they have not eroded the sediments completely to bedrock level in the Triangle area. Thus, the present water-bearing formations (aquifers) are under and adjacent to present surface streams and generally are not sealed off from them except by thin layers of mud and silt in this area. Even these sediments are periodically scoured out during floods and then replaced by others.

AREAS SUITABLE FOR DEVELOPMENT

The occurrence of water-bearing gravels in the Triangle area is shown on the map in Figure 1. The portion of the area presently developed by wells is defined on the map in Figure 4 by the locations of the producing-well symbols. Undeveloped portions exist toward the Point, where only a few wells have been drilled in the past and now are abandoned, and along the Monongahela River. Indications are that the Point area is as good as or better than others, owing to higher water levels, nearness to recharge, and distance from heavily pumped localities. Drilling records along the Monongahela River side of the Triangle area indicate that the aquifer is not as permeable there as in other locations, and the presence of low-yielding wells bears this out. The eastern limit of development of gravel wells is marked by the dotted line in Figure 1. This line has been defined by numerous dry holes and test borings which show that, to the east of the line, the gravel may be present but lies above the level of saturation. Along some segments of the line the gravel ends against the bedrock valley wall. Conditions favorable for the development of large supplies of ground water exist north of the Triangle area, in the area extending up the Allegheny River from the area shown on the map. Wells have been drilled along both sides of the Allegheny, Monongahela, and Ohio Rivers. The records of these wells are given in detail in Bulletin W 8.

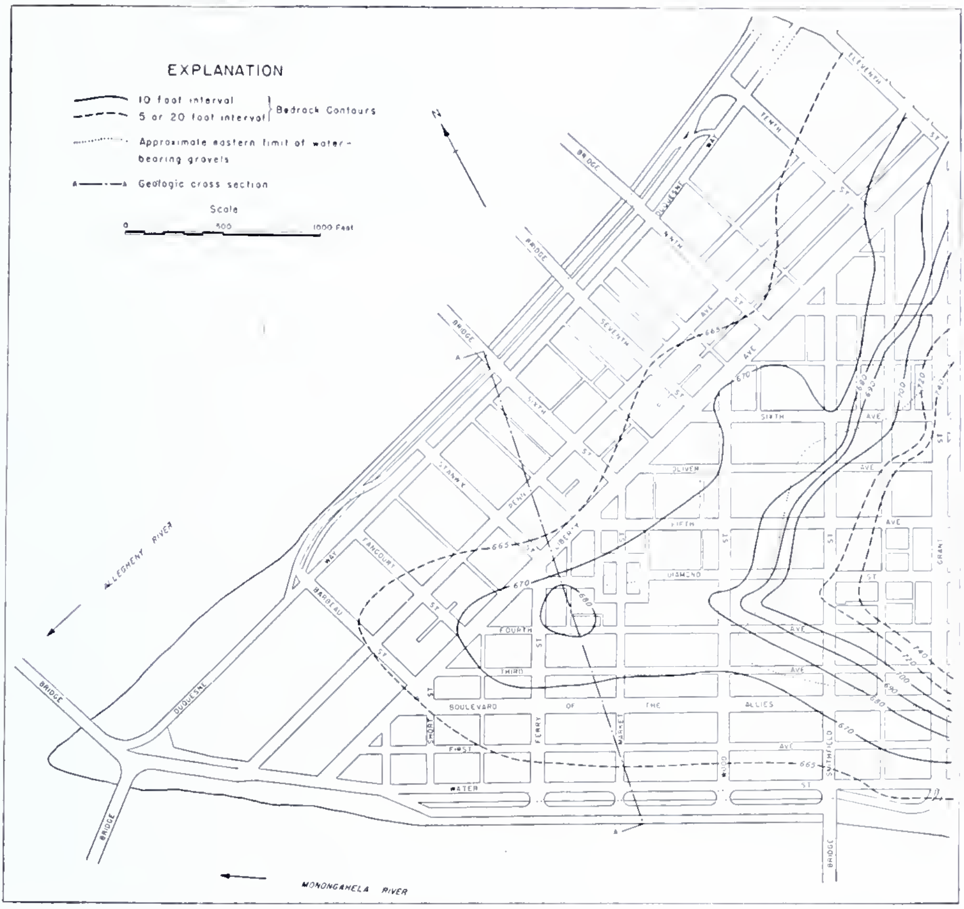

Figure 1. Map of Triangle area, Pittsburgh, showing contours on the bedrock surface, extent of water-bearing gravels, and location of geologic cross section A-A′.

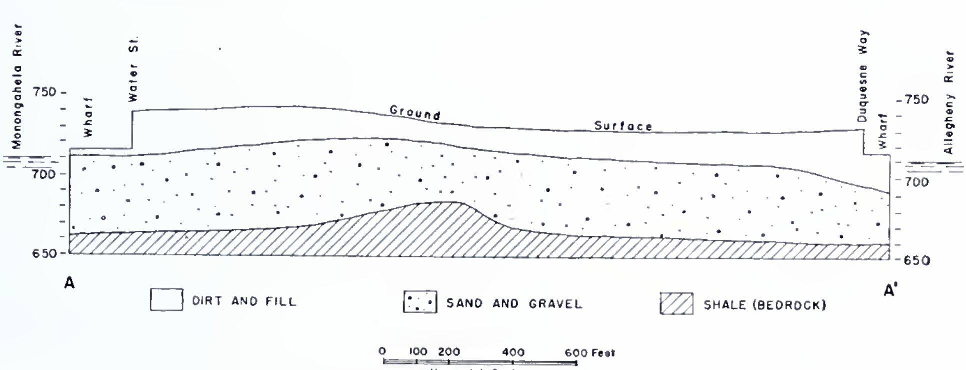

Figure 2. Geologic section across Triangle area, Pittsburgh.

In general, areas in which large amounts of ground water have been developed are suitable for some further exploitation. However, this is true only if total pumpage has not exceeded total recharge or the ability of the formation to transmit the amounts pumped. Overpumping results in excessive mutual interference among wells and in the lowering of water levels to or near the bottom of wells or the base of the aquifer. In some

instances, where recharge is small compared to pumpage, this lowering is permanent. In other instances, as at Pittsburgh, the lowering is temporary because total recharge is approximately equal to total pumpage year after year. The problem in the Triangle area is one of closely spaced wells being pumped heavily during a short period of time (summer), each increase in pumping causing additional lowering of the regional water table. Recharge during the non-cooling season is sufficient to cause the water table to return to normal levels.

HYDROLOGY OF GROUND-WATER SUPPLIES

In general, ground water occurs in two distinct types of aquifers: 1. The extensive geologic formation capable of storing large quantities of water and receiving recharge from some distant outcrop, through infiltration of precipitation or interception of surface water—generally artesian conditions prevail except in the areas of recharge and natural discharge. 2. The limited geologic formation in which the amount of storage is small but which may be capable of transmitting large quantities of water under imposed hydraulic heads from nearby sources of recharge; this type may be artesian or water-table or a combination of both. Naturally, there are many variations of these two general types. The aquifer underlying the Triangle area more nearly fits example 2. Extensive aquifers may contain hundreds of billions of gallons of water in storage, whereas the aquifer underlying the Triangle area has a storage capacity estimated at about 1,300,000,000 gallons. Not all this water is recoverable, however, as the aquifer never could be completely drained by any practical pumping arrangements. The storage available for extraction through wells is probably in the order of 500,000,000 to 800,000,000 gallons. These amounts can be withdrawn in 50 to 80 days with a regional pumping rate of 10 million gallons a day.

Storage capacity is only one of two controlling factors in the water-yielding capacity of the aquifer. The second is its permeability, or ability to transmit water through the pores of the sediments from points of high head to points of low head. This factor is evaluated in the coefficient of transmissibility, which is the flow in gallons a day through each vertical 1-foot strip of aquifer (top to bottom) under a hydraulic gradient of unity (100 per cent), or, in field terms, through a mile-wide section of the aquifer under a gradient of 1 foot per mile. Values of the coefficient are used in determining the estimated yield of a known aquifer. For example, in coarse, well-sorted gravels coefficients of several hundred thousand gallons a day per foot are not uncommon. In tight, small-grained deposits and in many consolidated rock aquifers such as some sandstones and limestones the values may range from only a few hundred to a few thousand. Some highly permeable aquifers such as cavernous limestone may have a coefficient of several million gallons a day per foot. Although never measured in the Triangle area by the usual method—pumping tests—the coefficient of transmissibility is estimated to be in the order of 100,000 gallons a day per foot.

Ground water occurs in the Triangle area under water-table conditions —that is, not confined under pressure. It is apparent that recharge to the aquifer is continuous from the adjacent rivers into the regional cone of

depression of water levels, at rates controlled by water temperature, hydraulic gradient, permeability, pumping rate, and amount of river-bed seal. For a given water temperature the permeability of the sediments at any one place (except at the river bottom) remains essentially unchanged, although the other factors are variable. It is also apparent that the rate of recharge is not equal to the summertime pumping rate, because water levels that are relatively high in winter and early spring are lowered 8 or 10 feet in a few weeks. This rapid drawdown of water level represents the establishment of a new hydraulic gradient large enough to allow water to flow through the sediments at this new pumping rate. At higher rates of regional pumping even lower water levels would be established. The limiting factor is that the relatively small thickness of saturated formation precludes further lowering of the water levels and resetting of pump intakes in this area.

CHEMICAL QUALITY AND TEMPERATURE

The chemical quality of ground water in the Triangle area is shown by the five analyses in Table 3. Additional analyses are given in Bulletin W 8, but only 3 of the 61 listed for Allegheny County are for the Triangle area.

TABLE 3. *Chemical analyses of ground water in Triangle area, Pittsburgh*
(Parts per million)

	1*	2†	3†	4†	5†
Date collected	1-9-48	1-19-51	1-19-51	1-19-51	1-19-51
Dissolved solids	535	218	406	330	503
Silica (SiO_2)	——	11	10	8.3	9.6
Iron (Fe)	.45	.64	.12	.04	.11
Calcium (Ca)	104	44	82	68	105
Magnesium (Mg)	24	8.0	11	9.2	16
Sodium (Na), Potassium (K)	——	20	37	26	42
Bicarbonate (HCO_3)	——	166	194	162	280
Sulfate (SO_4)	219	15	94	81	119
Chloride (Cl)	89	25	54	36	47
Fluoride (F)	——	.1	0	.1	.1
Nitrate (NO_3)	9.6	.6	3.3	4.8	2.5
Total hardness (as $CaCO_3$)	358	143	250	208	328
Hydrogen-ion concentration (pH)	7.4	7.0	7.2	7.2	7.1
Specific conductance (Microhms at 25° C.)	——	——	686	——	819
Temperature (°F.)	——	66	60	65	61

1. H. A. Speer Milk Co., 413 Market Street.
2. Josepb Horne Co., Stanwix Street and Duquesne Way.
3. Pennsylvania Railroad Co., Tentb Street.
4. Bell Telephone Co., Seventh Avenue and William Penn Place.
5. Weaver-Costello Co., 236 Boulevard of Allies.

* Analyzed by Pittsburgh Testing Laboratory.
† Analyzed by United States Geological Survey.

The ground water is satisfactory for most ordinary uses, including (so far as chemical character is concerned) drinking, and for practically all industrial uses with only slight treatment, such as softening, iron removal, or chlorination. The chemical quality of ground water in the Pittsburgh area is similar to that of the river water, its source. Variations in the concentrations of certain constituents in river water are reflected in similar variations in well water, as shown by data collected at Ambridge, on the Ohio River in Beaver County (Van Tuyl and Klein, 1951). The ground water generally is harder than river water and may contain objectionable iron and manganese. These differences in chemical character are due to the dissolving action of the recharging water in its passage through the ground. The ground water contains less suspended matter, has a higher pH, and is ordinarily not polluted although derived from a highly polluted source.

The relationship of the temperatures of ground water and surface water depends on several factors: Nearness of wells to source of river recharge, rate of pumping of the well, seasonal fluctuations of surface-water temperature (which are related to air temperature), and heat transfer and storage within the materials composing the aquifer. The temperature of natural ground water in Pittsburgh is about 53° F., where unaffected by river recharge. However, ground-water temperatures of wells in the Triangle area follow the pattern of seasonal fluctuations of river temperature, as shown by the graphs in Figure 3. In this illustration, ground water is represented by the graph of weekly temperature readings at the Joseph Horne Co. well (about 250 feet from the Allegheny River) during the air-conditioning season. Surface water is represented by the graph of mean monthly temperatures of the Allegheny River at the Pittsburgh Filtration Plant in Aspinwall (Industrial utility of water in Pennsylvania, 1947). The range in ground-water temperature has been from 48° to 73°, while the range in river temperature has been from 34° to 83°. The graphs in Figure 3 show that ground-water temperature lags 2 to 5 months behind the corresponding river temperature. It is also evident that during most air-conditioning seasons the ground water is cooler than the river water. The summer water-main temperatures of the Pittsburgh municipal supply, June to September, inclusive, range from 65° to 85° F.

No definite trend in ground-water temperatures appears in Figure 3. The record from the Horne Co. well for the period 1945-49 shows a gradual increase in both maximum and minimum temperatures, but there is no similar pattern in river-water temperatures. And in 1950 the maximum at Horne's was only 67°, which was 6 degrees lower than the maximum in 1949 and the lowest end-of-season temperature during the 14-year period of record. Whether this lower temperature in 1950 was caused by preceding or concurrent river temperatures is not determinable from the data presented. The decrease in ground-water temperature may be the result of less recharge during the period of high river-water temperature. It is estimated that pumpage in the Triangle area in the 1950 cooling season was approximately 8 per cent less than the pumpage in 1949 because of the differences in air-conditioning requirements.

No studies have been made of variation in temperature with location of wells in the Triangle area. It is believed, however, that seasonal fluctuations occur in all wells in the area, the range of magnitude probably

diminishing rapidly at increasing distances from the rivers. A gradual over-all increase in ground-water temperature from the normal of 53° F. probably has been contemporaneous with the increase in total ground-water pumping in the Triangle area, inasmuch as a large portion of the recharge that replaced the pumped water was at temperatures greater than the normal average ground-water temperature. A stabilized average temperature probably has been reached at about 60°, above and below which ground-water temperatures now fluctuate seasonally. This condition is unlike that in some other areas in the United States, in which ground-water temperatures are steadily increasing and may eventually reach a level considerably higher than 60° F., owing to the fact that recharge waters are at 80° and 90° in temperature (for example, see

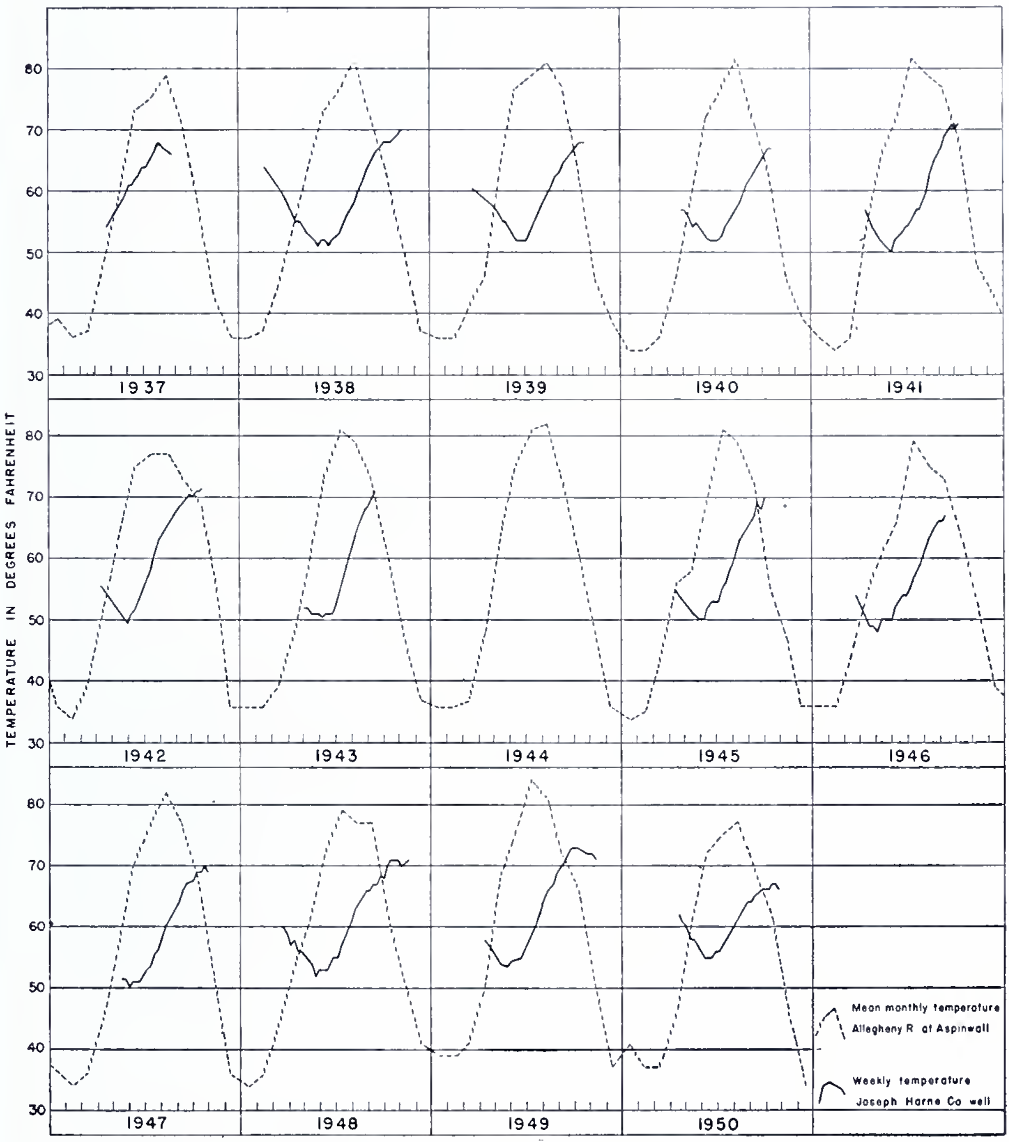

FIGURE 3. Graph showing fluctuations of temperature of well water and Allegheny River, 1937-50.

Leggette and Brashears, 1938). The possibility is remote that the long-term temperatures of natural recharge water to the aquifer in the Triangle area will increase greatly.

PRESENT DEVELOPMENT OF THE SUPPLY

HISTORY OF WELLS IN THE TRIANGLE AREA

The general use of modern drilled wells in the Pittsburgh area began about the turn of the twentieth century. Available records list four wells drilled in the Triangle area by 1900, and about 20 drilled between 1901 and 1910. More than half the known drilled wells in the Triangle area were installed after 1930. Some of the earliest wells contained either open-end pipe or perforated casing as screens in the aquifer, whereas later construction in general included commercially prepared screens designed for the thickness and type of water-bearing materials penetrated. Pumping equipment also became modernized, turbine and jet pumps replacing the air-lift and suction type. Today, compact electric motors drive equally compact deep-well pumps in the most modern wells.

A survey of wells by the City of Pittsburgh in 1931 reported 66 operating and 24 abandoned water wells in the Triangle area. Also included were 12 wells used for observation of water levels by the City during periods of high river levels. The well inventory by the U. S. Geological Survey reported in Bulletin W 8 listed 67 operating wells in 1948. Several changes have occurred since that inventory was made; the present status of water wells in the Triangle area is shown by symbols on the map in Figure 4. The history of wells is further illustrated by the data in Tables 4 and 5, which account for all known pumpage during the period 1930-50. The dates of drilling and abandonment of wells which were in operation during the 21-year period are shown, together with the individual pumpage.

INVENTORY OF PUMPAGE

Estimates by the U. S. Geological Survey of the amount of ground water used throughout the United States indicate that in the period 1935-45 the daily pumpage increased from about 10 billion gallons to more than 20 billion gallons (Guyton, 1949). The use in 1950 was estimated to be about 25 billion gallons a day (Guyton, 1950). Inventories of municipal and industrial use in many large metropolitan areas were used in these estimates. Data for Pittsburgh had never been compiled until Bulletin W 8 was prepared, and even that report was incomplete from an historical viewpoint. The present study not only delineates pumpage by years but also classifies it into two general categories. First is the inventory of ground-water use solely for air conditioning, and second is the inventory of pumpage for all other purposes, including drinking, sanitation, and all industrial processing and cooling.

The pumpage inventories in this report show that the use of ground water in Pittsburgh for air conditioning increased from zero in 1926 to more than 500 million gallons a year by 1949, and that total pumpage for all uses approximately doubled from 1930 to 1950. The increase during the period 1935-45 is computed to have been about 75 per cent.

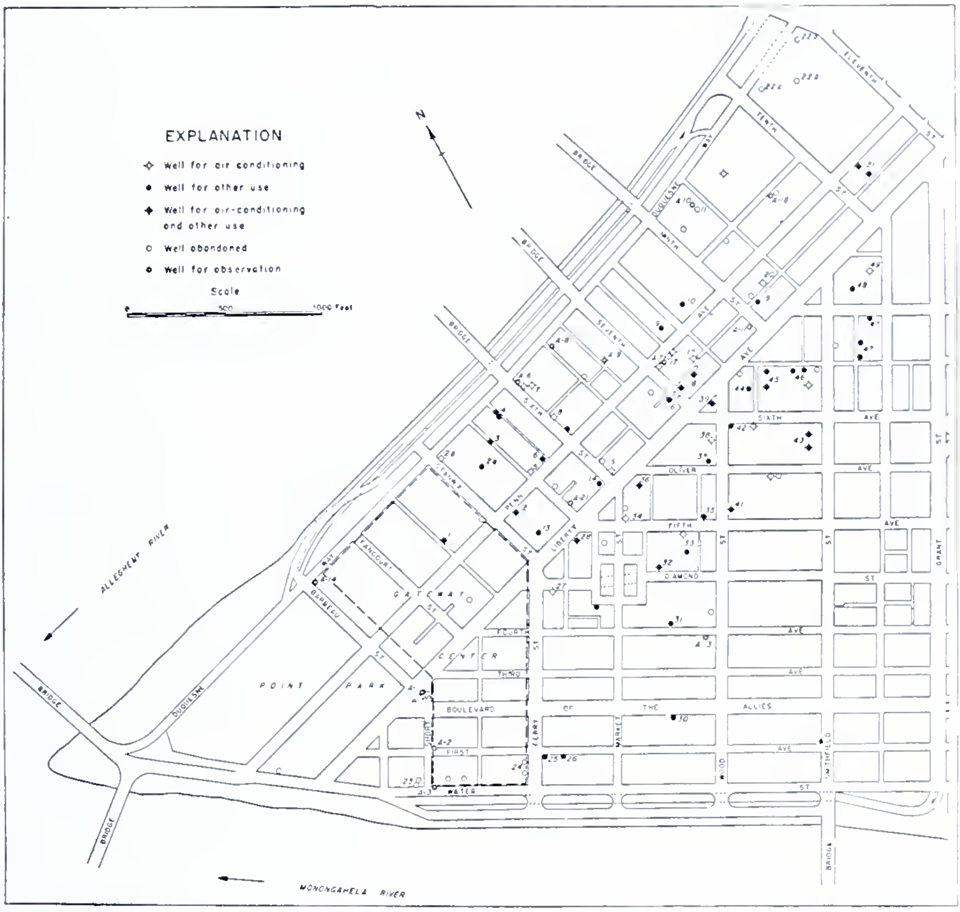

Figure 4. Map of Triangle area, Pittsburgh, showing location of wells and Point development projects.

Air-conditioning use

The use of ground water strictly for air conditioning at Pittsburgh began in 1927, the first such installation being at the Stanley Theater. Table 4 outlines the growth of air-conditioning use, listing the 32 ground-water installations in chronological order. No doubt many more places have installed air-conditioning equipment, but most of them use artificial refrigerants rather than well water, or in the larger systems municipal water recirculated through cooling towers. The volumes of ground water pumped have increased steadily since 1930 as new wells and new air-conditioning units have been added. Some of these obtained water from existing wells while others were supplied from new wells drilled specifically for the purpose.

The quantities of water shown in Table 4 were computed from information furnished by well owners and drillers, by multiplying the average daily rate by an estimated period of use. Average periods of operation per year were selected for the various types of places such as hotels, office buildings, department stores, and restaurants. Shut-downs on Sundays and holidays were considered. The actual time of operation was

known for Jenkins Arcade and the Stanley Theater. Pumpage by the Joseph Horne Co. for 1945-50 and by Gimbel's in 1950 was computed from actual pump operation and from water-meter readings. Changes in equipment capacity were taken into account at several places.

TABLE 4. *Individual pumpage for air conditioning, Triangle area, Pittsburgh*

Well Number*	Owner	Year Installed	Average Period of Operation *(days per year)*	Estimated Average Pumpage *(million gallons per year)*
17	Stanley Theater	1927	120	14.1
32	G. C. Murphy Co.	1931	150	32.4
27	McCann & Co.	1932	100	6.4
43	Oliver Building	1932	100	7.5
6	Stouffer's Restaurant	1934		10.0
33	Donahoe's	1935	100	10.8
41	Farmers Bank	1936	100	2.0
15	Woolworth Co.	1936	100	12.0
46	Gimbel's	1937	100	17.3
2	Joseph Horne Co.	1937	100	82.2
5	Walgreen Drug	1938	120	4.8
12	Jenkins Arcade	1939	100	2.1
36	Meyer-Jonassen Co.	1939	100	7.5
49	Senator Theater	1939	120	13.4
45	Duquesne Club	1940	120	6.5
20	May-Stern Co.	1940	100	7.2
21	Fort Pitt Hotel	1941	120	60.5
42	Spear & Co.	1941	100	28.8
18	Clark Building	1942	120	4.8
34	Hacke Building	1946	100	4.0
1	Mayfair Hotel†	1946	120	4.8
8	Roosevelt Hotel	1946	120	52.3
46	Gimbel's	1947	100	30.5
7	J. P. Harris Theater	1947	120	15.0
38	Hughes & Hatcher	1947	100	9.0
39	Max Azen, Inc.‡	1947	100	18.0
35	Peoples First Nat. Bank	1948	100	1.0
	Lane Bryant	1948	100	9.6
	Fulton Theater	1949	120	15.0
A-9	Century Building	1949	100	1.4
28	Pitt Bank Building	1949	100	4.0
	United Eng. & Foundry Co.	1949	150	16.8

* Well number on Fig. 4; same as given in Bulletin W 8.

† Used only in 1946.

‡ Used only in 1947.

The use of air conditioning, and consequently the demand for ground water, vary during the year. In general, air conditioning begins in April or May and ends in October, the exact times depending on local atmospheric conditions. The greatest demand corresponds to the hottest weather, whch generally occurs in July and August. Ground-water pumping reaches a maximum in the Triangle area during July, August and June being the next highest months. The seasonal distribution of pumpage is illustrated by the graph in Figure 5, which might be considered to represent a cooling-demand curve. The percentages by months are based on the six cooling seasons 1945-50, using the amounts pumped by the Joseph Horne Co., the largest user in the area. Figure 5 shows that nearly half the total withdrawal is made in July and August (about 27 per cent of the total in July and 21 per cent in August). The percentages shown for March and November represent pumping on an average of only 3 days in March and 3 days in November during each year of the 6-year period. Most wells are pumped nearly every day during June, July, and August, and most of September. The monthly values shown in Figure 5 may change somewhat over longer periods, in which temperature variations could be extreme. However, records of the U. S. Weather Bureau indicate that the mean monthly temperatures at Pittsburgh during the 6-year period 1945-50 do not differ greatly from the average for 77 years of record.

Other uses

The use of ground water in the Pittsburgh area has increased almost continuously since the first wells were drilled. Although complete pumpage data are not available for the entire period, the addition of new wells year after year is one indication. Also, this same situation exists generally throughout the United States, especially in those industrial areas where additional ground water is readily available (Sayre, 1948). In fact, the expansion of many industries is dependent on adequate supplies of suitable water. In this respect Pittsburgh is not an exception. The use of ground water there, however, has come into prominence after many industries were long established, as better equipment became available, as the value of ground water became better known, and with the impetus of two world wars.

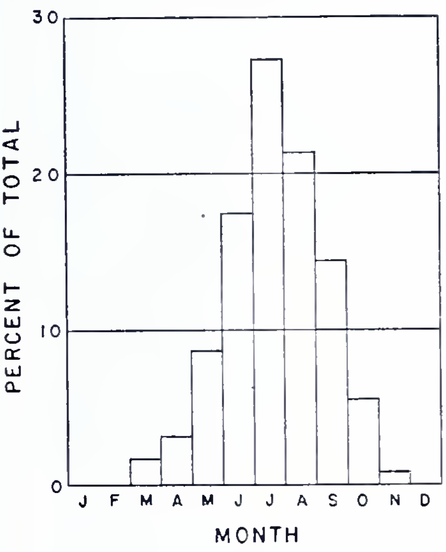

FIGURE 5. Graph showing average distribution of pumpage for air conditioning at Pittsburgh.

A detailed breakdown of pumpage in the Triangle area of Pittsburgh for all uses except air conditioning is shown in Table 5. The volumes were computed as outlined in the preceding section, using estimated average rates and periods of operation. Pumpage from new wells was added during the year they were reported drilled, unless it was known that operation began in a later year. Dates of abandonment were obtained from the

owners in most cases. Dates of abandonment of others were estimated from records of the use of metered water from the City of Pittsburgh. In a few instances the date of destruction of a building was considered the date of abandonment of the well. The first 27 wells in Table 5 are listed in the order of their abandonment; the remaining wells are listed in the order of well number as given in the original inventory in Bulletin W 8. The yearly pumpage for wells now in use are the estimated amounts for 1950.

TABLE 5. *Individual pumpage for uses other than air conditioning*

WELL NUMBER*	OWNER	YEAR STARTED	YEAR ABANDONED	TIME OPERATED (*days per year*)	YEARLY PUMPAGE† (*millions of gallons*)
	ABANDONED WELLS				
	Professional Building ...	‡	1933	300	1.2
	Arrott Power Building ..	‡	1934	300	2.1
	McCann & Co.	‡	1934	300	6.0
	National Biscuit Co.	‡	1934	365	17.5
A-9	Century Building§	‡	1935	300	3.6
	Spear Warehouse	1898	1935	300	3.0
	Point Building	‡	1935	300	2.1
	Moose Temple	‡	1935	300	4.5
	Heyl & Patterson	‡	1936	300	.6
	Post-Gazette Building ...	1903	1938	365	52.6
	Methodist Building	1907	1939	300	4.5
	Sherwin-Williams Co. ..	‡	1939	300	.3
A-11	Victory Building	‡	1942	300	2.1
	Arrott Building	‡	1942	300	3.6
	Shipley-Massingham	‡	1942	300	0.9
A-8	Pittsburgh Plate Glass Co.	‡	1944	300	2.4
	State Theater	[illegible]40	1944	300	1.2
A-13	Columbia Building	1908	1944	300	4.5
	U. P. Publications Bldg..	1908	1945	300	3.6
	Logan - Gregg Hardware Co.	‡	1945	300	.9
	Hacke Building	‡	1945	300	4.8
1	Mayfair Hotel	1946	1946	305	18.3
11	Duff & Sons	1916	1947	365	92.0
24	Pitt. & W. Va. R. R. ..	1908	1947	365	144.4
29	Speer Milk Co.	1935	1947	365	26.3
15a	Woolworth Co.	1916	1947	300	14.4
23	Union Storage Co.	1913	1949	365	160.0
	OPERATING WELLS				
2a	Joseph Horne Co.	1936		300	30.0
3	Allegheny Steam Heating Co.	1913		365	7.0
4	Manufacturer's Building.	1908		365	8.8
6	Stouffer's Restaurant ...	1934		300	10.8
8b	Roosevelt Hotel	1904		365	197.1
9	M. Bonn Co.	1893		300	1.4
10	Arbuthnot-Stevenson Co..	1910		250	1.3
12	Jenkins Arcade	1911		300	27.0
13	Empire Building	1900		300	7.2
14	Rosenbaum Co.	1914		300	28.8
16	Keenan Building	1912		280	10.1
18	Clark Building	1926		280	16.8

TABLE 5—*Continued*

WELL NUMBER*	OWNER	YEAR STARTED	YEAR ABANDONED	TIME OPERATED *(days per year)*	YEARLY PUMPAGE† *(millions of gallons)*
	OPERATING WELLS—Continued				
19	Renshaw Building	1907		280	6.3
21	Fort Pitt Hotel	1915		365	211.7
22	Pennsylvania R. R.	1939		365	578.0
25	Tranter Manuf. Co.	1908		300	.5
26	Pitt. Trolley & Forge	1916		300	3.6
27	McCann & Co.	1932		300	39.6
28	Pitt Bank Building	1926		280	4.2
30	Weaver Costello & Co.	1902		365	8.8
31	Benedum-Trees Building	1906		300	4.5
32	G. C. Murphy Co.	1931		300	64.8
33	Donahoe Co.	1923		300	21.6
35	Peoples First Nat. Bank	1900		280	16.8
36	Meyer-Jonassen & Co.	1922		300	13.5
37	Hardy & Hayes Building	1910		300	4.8
39	Max Azen, Inc.	1947		250	36.0
41	Farmers Bank Building	1904		280	16.8
42a	Spear & Co.	1924		300	18.9
43	Oliver Building	1909		300	45.0
44	Eastman Kodak Co.	1915		100	.2
45	Duquesne Club	1910		365	31.5
46	Gimbel's	1910		300	36.0
47a	Bell Telephone Co.	1906		365	6.6
47b	Bell Telephone Co.	1941		50	.6
47c	Bell Telephone Co.	1942		365	27.4
48	Chamber of Commerce	1916		300	16.2
	Speer Milk Co.¶	1948		365	7.2

* Well number on Fig. 4; same as given in Bulletin W 8.
† Estimated; see pp. 15 and 16 for explanation.
‡ Before 1930; exact year not known.
§ Pumping resumed June 1949.
¶ Operating well abandoned by Mc [illegible] in 1934.

A composite of the data from Tables 4 and 5 is given in Table 6, which lists the total and average daily pumpage for the two classifications of use for each year since 1930. Air conditioning accounts for a fairly high proportion of the total pumpage of ground water in the Triangle area. The amount used during 1950 was about 25 per cent of all pumpage. Considered on a maximum daily-rate basis, air-conditioning use was nearly equal to all other uses, or about 50 per cent of the maximum rate of pumping. This represents a great increase since 1940, at which time the yearly volume was only 10 per cent of the total and the maximum daily rate was about 25 per cent of the total.

Differences in the yearly pumpage figures are due not only to additions of new units and changes in unit capacities, but also to variations in the cooling requirements depending on the climatic conditions. The differences relating to temperature variations are difficult to evaluate and have not been considered, except in those instances where actual pumpage records, which reflect these variations, have been used in the tabulations.

The yearly totals from Table 6 were used in preparing Figure 6, which

TABLE 6. *Ground-water use in Triangle area, 1930-50*

YEAR	AIR-CONDITIONING USE			OTHER USES		
	No. of units	*Million gallons per day*	*Million gallons per year*	*No. of wells*	*Million gallons per day**	*Million gallons per year*
1930	1	0.12	15.0	54	3.85	1,305
1931	2	.34	47.4	55	4.01	1,353
1932	4	.48	61.3	56	4.13	1,389
1933	4	.48	61.3	56	4.19	1,409
1934	5	.58	71.3	56	4.21	1,412
1935	6	.69	82.1	54	4.22	1,416
1936	8	.85	96.1	52	4.25	1,420
1937	10	1.67	180.1	52	4.20	1,406
1938	11	1.71	184.9	53	4.05	1,352
1939	14	1.95	207.8	54	5.94	2,045
1940	16	2.08	222.7	54	6.59	2,280
1941	18	2.91	314.6	55	6.60	2,282
1942	19	2.95	318.9	56	6.67	2,307
1943	19	2.95	318.5	53	6.66	2,302
1944	19	2.92	315.6	53	6.64	2,299
1945	19	2.84	306.0	50	6.62	2,293
1946	22	3.71	404.4	51	6.64	2,299
1947	26	4.28	466.8	53	6.50	2,236
1948	28	4.57	498.7	51	6.04	2,051
1949	32	4.85	533.6	54	5.72	1,933
1950	32	4.47	491.7	53	4.60	1,523

* Figures in this column represent average daily use during the year; rates of total use during air-conditioning seasons are the sums of these figures and the daily air-conditioning rates.

shows graphically the annual pumpage for air conditioning and other uses for the period 1930-50. The length of the bar for each year marks the total amount of ground water pumped for all purposes.

Bulletin W 8 contains records of about 300 wells in Allegheny County, but apparently very few outside the Triangle area are used for air conditioning. The Triangle area contains a concentration of buildings in which large numbers of people work or congregate, and it is there that comfort air conditioning has been most widely applied. The few known establishments outside the area that use ground water for air conditioning are listed in Table 7.

EFFECTS OF PUMPING ON WATER LEVELS

Water-level records

A program of observation of water levels in the Triangle area has been in operation since 1945, under the Federal-State cooperative arrangement. As part of the base data necessary in evaluating the ground-water resources of the area, water-level records serve as an index of the storage in the aquifer. A decline in water level indicates a reduction in the amount

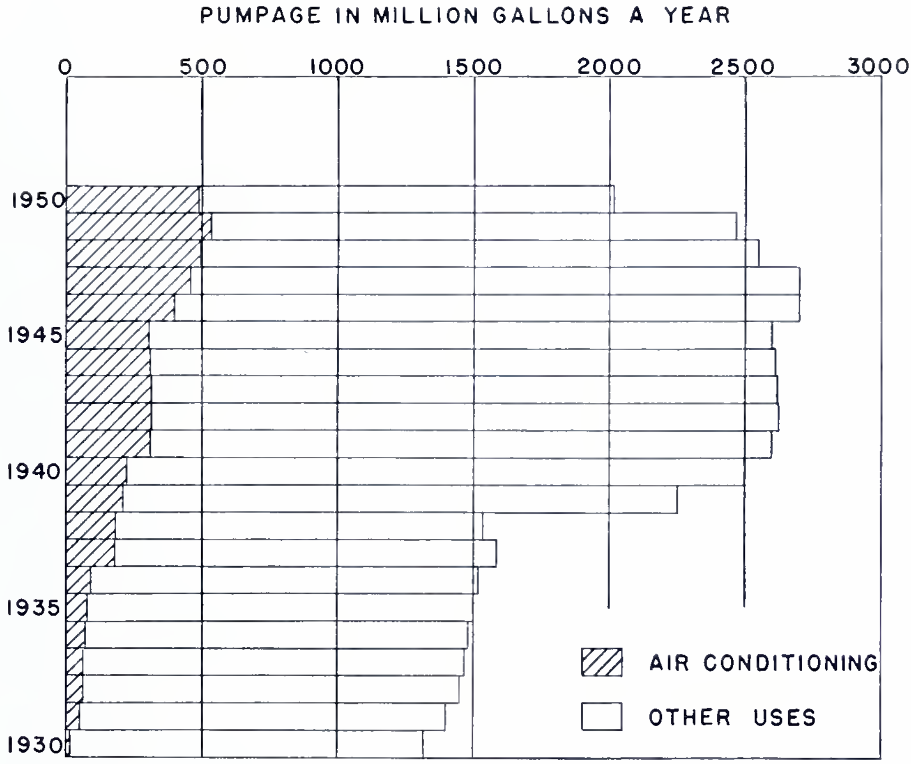

Figure 6. Graph showing annual pumpage for air conditioning and other uses, Pittsburgh, Pa., 1930-50.

of stored water, and a rise in water level indicates an addition or recharge to the aquifer.

Records of the water levels in four typical observation wells in the area are shown by the graphs in Figure 7. The locations of these wells are shown in Figure 4. These records are fairly representative of the fluctuations throughout the Triangle area and they show a seasonal regularity. The highest water levels generally occur in late winter and early spring, and the lowest water levels occur in the summer and early autumn.

Table 7. *Pumpage for air conditioning outside Triangle area*

Number*	Owner	Location	Pumpage†	Remarks
119	Pittsburgh Screw & Bolt	North Side	6.5	Gravel wells
139	Dravo Corp.	Neville Island	7.2	Gravel well
	Arcade Theater	South Side	2.5	Rock well
	Boggs & Buhl	North Side	3.6	Rock well
	Buhl Planetarium	North Side	4.2	Rock well; 1938-49 only
	May-Stern Co.	E. Liberty	3.2	Rock well
	McKeesport Daily News	McKeesport	3.5	Rock well; 1937-44 only
	Parkway Theater	McKees Rocks	7.2	Rock well
61	Kerotest Mfg. Co.	2 mi. northeast of Triangle area	1.4	Rock well

* Well number as given in Bulletin W 8.

† Approximate pumpage in million gallons a year.

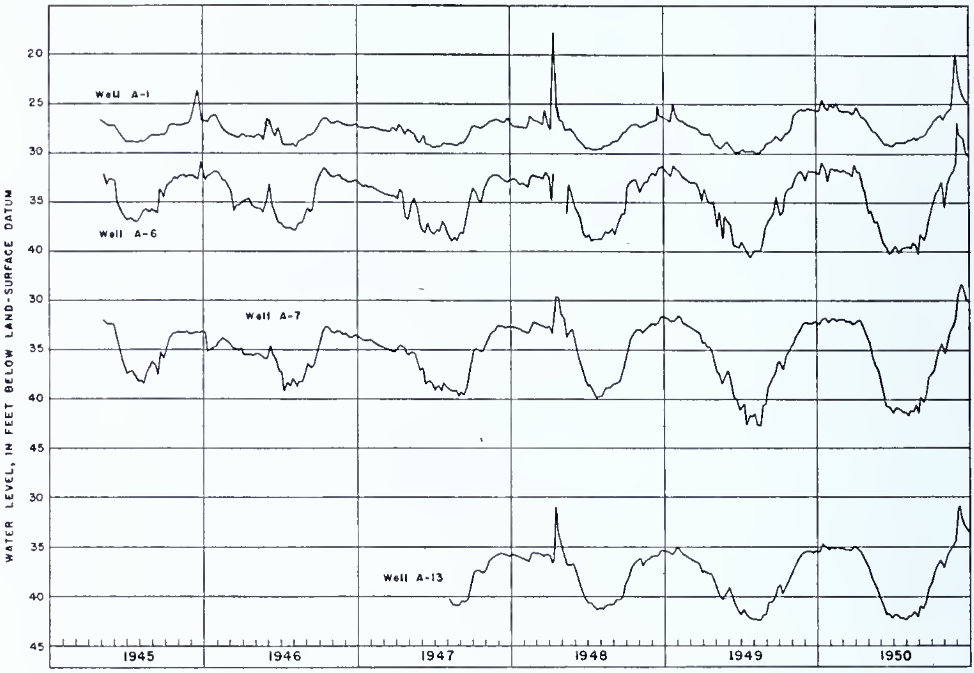

FIGURE 7. Graph showing fluctuations of water levels in observation wells, Pittsburgh, Pa., 1945-50.

This pattern of fluctuation represents in part the additional warm-weather pumpage for cooling purposes, especially air conditioning. The largest rises, in April 1948 and December 1950, were caused by very rapid recharge during periods of unusually high river stage. Thus, the aquifer at these times was refilled in a very few days, whereas normally it is refilled slowly during the winter period to approximately equal levels year after

TABLE 8. *Highest and lowest water levels in observation wells, Pittsburgh, Pa., 1945-50*
(Elevations in feet above sea level)

Number*	Name	Highest Water Level		Lowest Water Level		Record Started
		Elev.	Date	Elev.	Date	
A-1	City of Pittsburgh	713.26	4-15-48	700.90	8-18-49	5-1-45
A-2	City of Pittsburgh	713.74	4-15-48	701.36	8-18-49	9-7-45
A-3	City of Pittsburgh	715.34	4-15-48	702.11	3-16-46	5-25-45
A-6	Fulton Building	706.19	12-5-50	692.35	7-28-49	5-8-45
A-7	Stanley Theater	702.77	12-12-50	688.26	8-18-49	5-8-45
A-8	Pittsburgh Plate Glass Co.	707.23	4-16-48	694.70	6-29-50	5-23-46
A-9	Century Building	705.24	4-15-48	694.52	7-22-48	5-23-46†
A-10	Atlas Paste Co.	700.30	4-22-48	687.32	8-1-46	5-23-46
A-11	Victory Building	702.62	12-14-50	689.82	8-3-50	5-23-46
A-13	Columbia Building	705.72	12-10-50	693.96	7-1-50	8-7-47
A-14	City of Pittsburgh	723.32	4-15-48	705.02	7-14-49	4-24-45
A-18	Federal Drug Co.	700.05	12-12-50	687.91	8-3-50	3-28-49

* Well number on Fig. 4.
† Measurements discontinued 6-2-49.

year. The rate and magnitude of summer declines are functions of the rate and magnitude of regional pumping.

The graphs in Figure 7 indicate that successively lower water levels were reached each summer from 1945 to 1949. This trend did not continue in 1950 in these selected observation wells, however, although new lows were recorded in four other wells in the Triangle area, as shown in Table 8. The reversal of trend can be attributed to an 8-per cent reduction in pumping for air conditioning in 1950, owing to lower cooling requirements. It is evident that the lowest water levels each year are related more closely to the volume of pumpage for air conditioning than to the total pumpage during the year. The graph in Figure 6, when compared with Figure 7, illustrates this quite clearly.

The highest and lowest recorded water levels in 12 observation wells in the Triangle area are listed in Table 8.

Contours on the water table

The nature and extent of the regional cone of depression of water levels are shown by Figures 8 and 9. These show by contours the position of

TABLE 9. *Ground-water elevations in Triangle area, January 5 and August 17, 1950*
(Elevations in feet above sea level)

Well Number*	Name	January 5, 1950		August 17, 1950		Difference (feet)
		Depth to water (feet)	Elev. (feet)	Depth to water (feet)	Elev. (feet)	
A-1	City of Pittsburgh	25.70	705.24	28.63	702.31	2.93
A-2	City of Pittsburgh	26.24	705.60	28.88	702.96	2.64
A-3	City of Pittsburgh	24.60	705.90	26.53	703.97	1.93
A-6	Fulton Building	19.02	700.83	25.90	693.95	6.88
A-7	Stanley Theater	16.46	698.65	25.24	689.87	8.78
A-8	Pitt. Plate Glass	20.14	701.86	26.70	695.30	6.56
A-10	Atlas Paste Co.†	20.70	696.90	27.45	690.15	6.75
A-11	Victory Building	14.80	698.80	23.33	690.27	8.53
A-13	Columbia Building	23.54	701.06	30.18	694.42	6.64
A-14	City of Pittsburgh	15.20	708.45	17.80	705.85	2.60
A-18	Federal Drug Co.	26.28	695.72	33.62	688.38	7.34
A-21	May Building	15.90	700.20	23.60	692.50	7.70
15a	Woolworth Co.	22.21	699.79	30.60	691.40	8.39
16	Keenan Building	20.88	700.52	——	——	——
23b	Union Storage Co.	——	——	25.56	703.70	——
27	McCann & Co.	18.30	701.50	22.72	697.08	4.42
37	Hardy & Hayes	——	——	20.24	689.76	——
43	Oliver Building	17.50	698.20	——	——	——
46b	Gimbel's	9.27	698.73	18.68	689.32	9.41
47b	Bell Telephone Co.	35.08	697.62	43.70	689.00	8.62
	City of Pittsburgh	30.04	700.76	——	——	——
	Point Building	11.80	708.22	13.92	706.10	2.12
	United E. & F. Co.	35.08	694.43	42.08	687.42	7.00

* Well number on Fig. 4; same as given in Bulletin W 8.
† Formerly Duff & Sons.

the water table on two dates in 1950. Figure 8 was drawn on the basis of measurements made on January 5, and Figure 9 on measurements made on August 17. Approximately 23 individual wells were used in determining the elevations listed in Table 9. On January 5 the water table was near its highest level of the year in most wells (neglecting the unusual rise later in December), and on August 17 it was near the seasonal low level.

The contours show in a general way the direction of flow of ground water, which is always from high elevations to low elevations and at right angles to the contour lines. The contour maps show the localities in the Triangle area of lowest water levels, which correspond to the greatest drawdowns due to wintertime and summertime pumping. In January the lowest area was centered in the vicinity of the Pennsylvania Railroad wells, extending toward the Stanley Theater and the Clark Building and the vicinity of Sixth Street. The closely spaced lines represent steep hydraulic gradients and high rates of ground-water flow, from the Point of the Triangle and from the Allegheny River just below Sixth Street. The delineation is incomplete, however, owing to the scarcity of observation wells at certain strategic points, especially along the Allegheny River. There is little or no flow from the valley-wall side of the depression or into the Triangle from north of Eleventh Street. Similarly, the contribu-

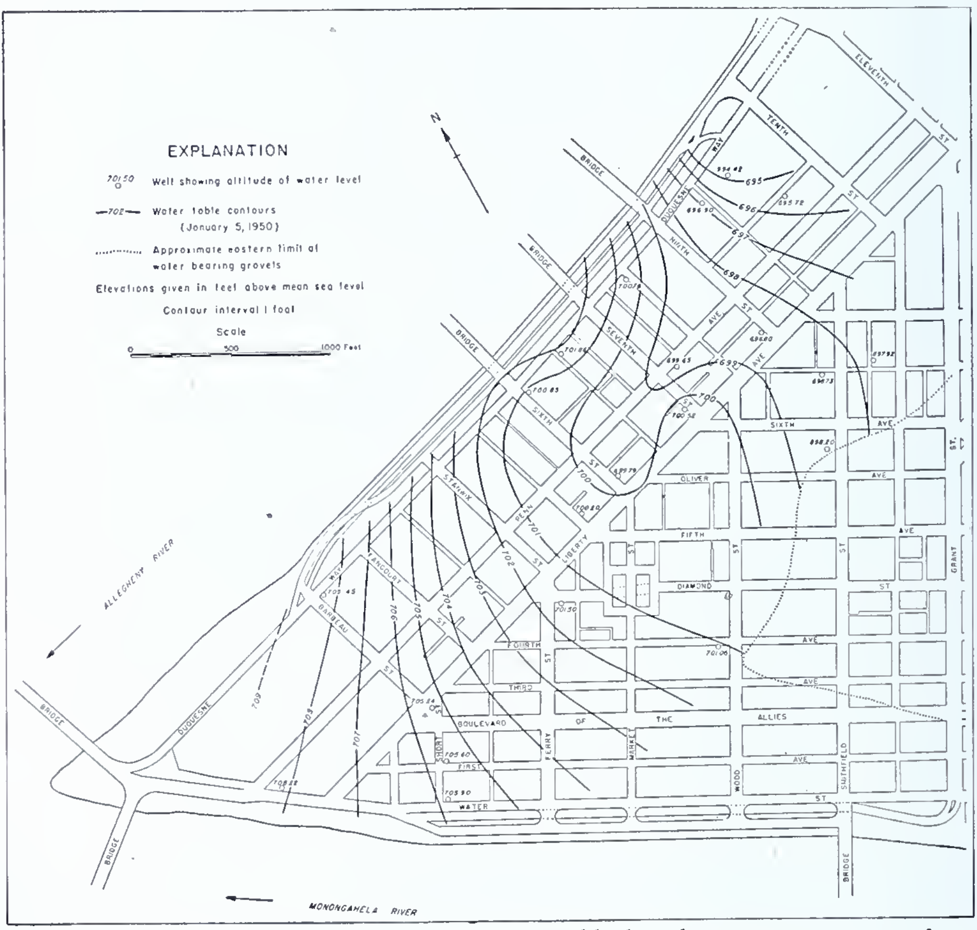

FIGURE 8. Map showing contours on the water table based on measurements of water levels on January 5, 1950, Triangle area, Pittsburgh.

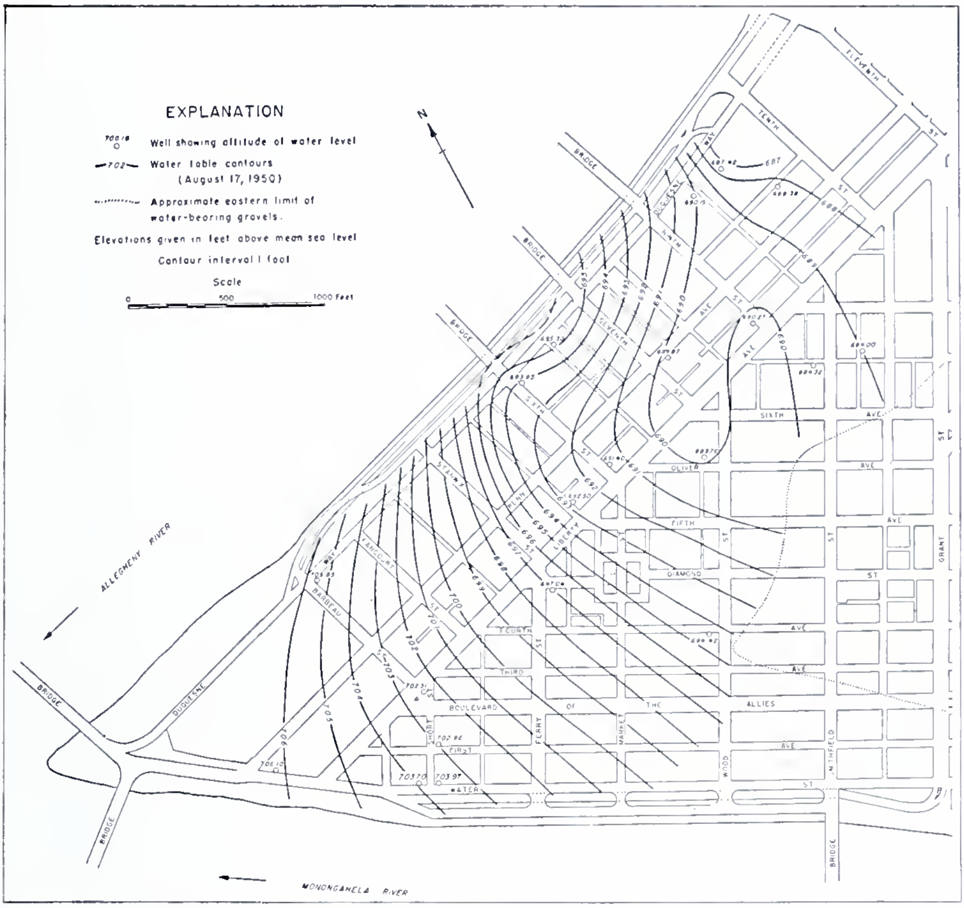

FIGURE 9. Map showing contours on the water table based on measurements of water levels on August 17, 1950, Triangle area, Pittsburgh.

tion from the Monongahela River is small, on the basis of the contoured elevations.

Referring to Figure 9, the lowest water levels on August 17 were at the upper end of the Triangle area, in the vicinity of the Pennsylvania Railroad wells (no. 22 on fig. 4). A trough of low elevations extends from there toward Oliver Avenue and the region occupied by Gimbel's, Spear's, and the Duquesne Club. The net decline of water levels in that area between January 5 and August 17 averaged at least 9 feet. In the part of the Triangle area north of Stanwix and Diamond Streets the net decline was greater than 6 feet.

The contours in Figure 9 indicate that recharge water is flowing into the regional cone of depression principally from the Point area, under a total difference in head of at least 17 feet. The average hydraulic gradient in this direction is approximately 0.67 per cent, and the maximum gradient—along the Allegheny River below Sixth Street—is about 1.6 per cent, on the basis of the contours in Figure 9.

A comparison of the contours in Figures 1 and 9 shows that water levels have been drawn down to within 10 or 15 feet of the bedrock surface in the center of the depression. Two factors contribute to this condition: 1. The concentration of heavy pumping is relatively distant from the

sources of river recharge. 2. The aquifer in this section of the Triangle area is narrower than in sections nearer the Point. It should be remembered, incidentally, that the water levels shown in Figures 8 and 9 were determined from measurements in non-operating wells, and that the water levels in producing wells are several feet lower than those shown by the contours.

FACTORS AFFECTING THE SUPPLY

CHANGES IN PUMPING

Ground-water conditions in the Triangle area of Pittsburgh, as shown by data presented in this report, reflect the steadily increasing withdrawal from new wells. The concentration of pumping from the relatively shallow aquifer of limited areal extent has produced a year-round regional cone of depression of water levels, in which the water table approaches the limit of feasible drawdown during the air-conditioning season. The history of well operation indicates that as new wells are put into service older ones are being abandoned, but the over-all trend is one of increasing pumping. It is evident that new wells or increased pumping in the "low" areas will cause additional lowering of the water table. This would affect the yield of all wells in the area, to such an extent that some owners probably would consider abandoning their ground-water supplies. Thus, a practical balance may be maintained almost automatically. Likewise, new wells in the area away from the present low points—in the Point region, for example—would ultimately affect all others by lowering water levels and reducing the hydraulic gradients toward the present concentrations of pumping. In effect, wells around the periphery of the "cone" would intercept the recharge now flowing from the river sources to wells in the depressed area. However, such wells could induce a greater total amount of recharge because the gradient of the water table toward them would be steeper.

It has been pointed out that the aquifer underlying the Triangle area is one of small storage capacity. The limiting factor therefore becomes the ability of the formation to transmit recharge water at adequate rates under existing or maximum possible hydraulic heads. This factor cannot be changed greatly because the permeability of geologic formations is relatively constant. It is concluded, therefore, that maximum recharge has been approached under the existing conditions of geology, hydrology, well distribution, and pumping rates. If the ultimate cone of depression has been produced, additional ground water cannot be obtained from the present wells within the area unless the aquifer is recharged artificially.

Two large reductions in pumping were made at opposite ends of the Triangle area in 1949. Pumping by the Union Storage Co. (well 23) was stopped completely in November, and that by the Pennsylvania Railroad (well 22) was greatly reduced, by about 35 per cent, in September. The total reduction amounted to about 490 million gallons a year, or an average of 1.3 million gallons a day. This benefits other well owners throughout the Triangle area. This amount of pumpage could now be replaced by a number of new small-capacity wells adequately spaced in either of the two localities without lowering the water level as much as the heavier pumping did previously.

The long-term trend of summertime pumping cannot be predicted, but three possibilities can be considered: 1. If ground-water demands increase, a limit will be reached with only slight additional pumping; 2. If the demand remains constant, as of 1950, additional small-yielding wells can be installed, preferably at sites away from the present center of large drawdown, the closer to the Point or the Allegheny River the better; 3. If demands decrease or existing wells are abandoned, additional pumping will be possible in all locations, but again preferably away from the deepest depressions in the water table.

BARRIERS TO NATURAL RECHARGE

Natural recharge of water supplies originates as precipitation on the land surface, through which it seeps down to the permanent water table and becomes part of the ground-water body. Part of the rainfall flows over the land surface and enters the streams and rivers, where it may be available for recharging ground-water reservoirs if the proper conditions exist. Natural and man-made barriers exist in the Triangle area so that recharge is limited.

A large percentage of the land in the Triangle area is covered by impermeable materials which prevent the direct infiltration of rain water into the ground. Such areas include buildings, streets, sidewalks, and paved parking lots. The direct contribution by rainfall to the ground-water supply of the Triangle area is negligible.

The geologic boundaries of the aquifer prevent any appreciable recharge from precipitation and underflow from adjacent land areas. The most effective boundary is the rock wall of the preglacial valley along the eastern edge of the Triangle area and against which the saturated part of the formation terminates abruptly, as shown in Figure 2. The more distant valley walls, across the Allegheny and Monongahela rivers, probably are not effective, owing to the presence of the surface sources of recharge between them and the pumped area.

The most important barrier to recharge in the Triangle area is a work of man, constructed only a decade ago. It consists of a continuous sheet-pile cut-off wall along the Allegheny River from Eleventh Street to a point opposite Barbeau Street—a distance of about 3,750 feet. The steel sheet-piling was installed as underpinning for the outer wall of the river wharf during construction of the Duquesne Way underpass and the wharf, in 1940. It extends to a depth averaging about 33 feet below normal river level. The following list gives the elevations of the wharf features and the aquifer limits:

Top of river wharf	714 feet
Normal pool, Allegheny River	710
Bed of Allegheny River	700
Surface of gravel aquifer	690-695
Bottom of sheet-pile wall	677
Surface of bedrock	662

The effect of the cut-off wall on recharge is a reduction of the cross-sectional area of inflow to about half its former area. Instead of an original 32 to 37 feet of aquifer thickness, only the lower 15 feet remains open for the transmission of recharge water. That a decrease in the amount

of recharge must have occurred is obvious. Although no summer-season water-level data are available for the period prior to 1940, it would appear that the regional water table has been lowered as a result of the wharf construction. Individual well owners have stated that their wells yield less water than formerly or that the pumping level has been lowered since 1940. The shape of the contour lines on Figures 8 and 9 indicates an absence of large recharge along this reach of the Allegheny River, whereas a larger volume of flow appears to enter from beyond the south end of the wall.

The condition outlined above is of major importance with respect to ground-water use in the Triangle area. The imposed barrier has definitely decreased the effectiveness of the Allegheny River as a source of recharge and has reduced the capacity of the aquifer to yield large volumes of water to wells. The depressed roadway and wharf along Water Street on the Monongahela River side was built on spaced wood piles which reduced the cross section of inflow only slightly.

Of even greater significance, perhaps, than the existing barrier is the proposal to continue the Allegheny River wall completely around the Point of the Triangle, as part of the riverside improvements in the State Point Park project. Such construction would reduce the effectiveness of river recharge an estimated 50 per cent over an additional 3,500 feet of river front. The present high water levels in the Point area would be lowered and the hydraulic gradient toward the center of the Triangle area would be reduced. Less ground water would be moving into the underground storage reservoir. Pumping would have to decline owing to excessive drawdowns, and some wells would have to be abandoned. Eventually, however, a new stabilized water table would appear, based on average pumping rate equal to the new average recharge rate.

The presence of cut-off walls around the Triangle area was a primary factor in determining the feasibility of using ground water for air conditioning the proposed new office buildings in the Gateway Center project. The designers have rejected a plan to test drill for ground water for this purpose. An air-conditioning system to serve from five to eight skyscrapers would require up to 11,000 gallons a minute of water at a temperature of 70° F. It is doubtful that this quantity would be available from wells in the Point area under the proposed cut-off conditions.

TEMPERATURE CHANGES

The record of ground-water temperatures obtained from the well of the Joseph Horne Co. is the only available index of the temperature factor in the Triangle problem. As pointed out in a previous section, the expected range of ground-water temperature is from 48° to 75° F. under present pumping and recharge conditions. If the maximum temperature eventually becomes higher, many well owners may be expected to consider abandonment of ground water for air conditioning and other cooling purposes. To compensate partially for such loss of cooling power, ground-water supplies could be augmented with city water near the end of each season, reducing water temperatures by means of cooling towers. A well owner who continued to use only ground water would encounter a serious situation. If his air-conditioning system required 330 gallons of water a

minute at 60° F., about 430 gallons a minute at 70° F. and 730 gallons a minute at 80° F. would be required to do the same amount of cooling. Thus, as the temperature increased, pumping would increase. Because additional recharge would be induced at a time when the river water is warm, the increase of pumping would cause temperatures to climb further, and in turn the water requirement would increase again. Although not an endless cycle, this illustrates the progression of events that would occur if ground-water temperatures increased.

The ultimate effect of successively higher ground-water temperatures probably would be a net decrease in regional pumping, owing to gradual abandonment of wells used for air conditioning. This might result in a gradual return of water temperatures to the present range of fluctuation. It is believed, however, that no substantial lowering of present summertime temperatures would follow any but a radical reduction in regional pumping.

The rate of movement of water through an aquifer is inversely proportional to its viscosity, which is approximately proportional to its temperature. Warm water has a lower viscosity and thus will flow more easily than cold water. The permeability of a given aquifer therefore varies with the temperature of the water passing through it. The viscosity factor results in higher rates of recharge in summer than in winter, other factors being constant. In the Triangle area this condition is favorable from the standpoint of quantity of water but unfavorable from the standpoint of temperature of the water. The effects of temperature and viscosity on recharge involve a complex experimental and mathematical study, beyond the scope of this report.

FLUCTUATIONS OF RIVER STAGE

The elevations of the rivers adjacent to the Triangle area are controlling factors in determining the hydraulic gradient toward the wells in the area. With a regulated river level and a limit on drawdown in the aquifer, a maximum head is established and the rate of flow of water into the aquifer is constant except as affected by temperature. This condition exists in the Triangle area until the river stages rise as the result of heavy rains and flood flows. Substantially greater heads are produced as the rivers rise, and the inflow rate increases, refilling the depleted storage in the aquifer, as shown by the records of water levels in the observation wells (fig. 7). Thus water that has been drained by heavy pumping during several months may be replenished in a few days of unusually high stream flow. The time of year at which large river rises occur has a bearing on the net effect on ground-water levels. The flood flows in April 1948 increased ground-water supplies at the beginning of the cooling season, maintaining high water levels later in the season than otherwise would have been the case. The flood flows in December 1950 came as ground-water levels were recovering at normal rates from summer lows. In this case, however, the gain in storage was temporary—mostly above the normal "full-storage" level of the aquifer—and water levels dropped again to seasonal positions as part of the water recharged from the river flowed back into the river.

ALLEGHENY COUNTY SANITARY AUTHORITY

At present Pittsburgh has no municipal system for sanitary sewage treatment. Practically all sewage and industrial wastes are discharged untreated into the streams. The water used in the Triangle area, whether obtained from individual wells or from the city supply, also is discharged into the adjacent rivers. It is well known that the major rivers in western Pennsylvania are highly polluted.

The establishment in 1946 of the Allegheny County Sanitary Authority, under the Municipal Authorities Act, constitutes the first real large-scale attempt to clean up the local pollution problem. This Authority will collect and treat all municipal sewage and wastes in the Pittsburgh area (Allegheny County Sanitary Authority, 1948). Sewage service charges will be based on water use at rates varying with the amount of water. The charges to users of metered city water will be easily established, and special arrangements will be made with those using private well supplies. Several questions are involved in this procedure: 1. The measurement of the quantity of well water discharged into the sewers; 2. The advisability of putting this unpolluted water into the sewers, to be transported and treated at unnecessary expense to both the well owner and the Authority; 3. The effect of sewer-service charges on well operation—whether knowledge of the quantities involved and the charges to be made will cause well owners to cut down or control more closely their pumping. The operations of the Allegheny County Sanitary Authority may result in decreased pumping from wells in the Triangle area. At the least, the new regulations will make more ground-water users aware of their pumping rates and disposal costs.

An alternative to the disposal of air-conditioning water into sewers is the use of recharge wells through which unpolluted water is returned to the underground formation. Similar in effect to a recycling process, the ground water could be used over and over, thereby greatly reducing the net withdrawal. Individual disposal wells in the Triangle area would make it unnecessary for the owners to pay the sewer tax on the water disposed but would create other problems affecting the supply of ground water. The operation of return wells and the factors involved in their use in this area are discussed more fully in a later section.

METHODS OF CONSERVING THE SUPPLY

REDUCTION OF WASTE

The most obvious method of ground-water conservation is the reduction of pumping to the smallest amount needed. In most cases this is done as a matter of economy of operation, but in some instances maximum use of the pumped water is not made. Unless the greatest possible economical use of ground water is made, the supply is being wasted. One of the first steps in waste reduction is the use of proper controls. A water-supply system subject to volume and temperature control, either automatically or manually operated, is generally the most efficient and doubtless most conservative of the supply. A pure water that has been changed only by warming it a few degrees remains pure and usable for many other purposes.

In air-conditioning use, ground water can often be conserved by reuse. The cooling effect of spraying discharge water on the roof of a building can reduce the air-conditioning tonnage required for the system. In some cases the discharge water can be used for precooling the outside air, thus increasing the amount of heat added to the water and reducing the water requirement. In manufacturing establishments waste ground water from an air-conditioning system can be used for further cooling of air compressors and engines, or used for sanitary or other purposes in the plant.

Two of the best methods of conserving water are recirculation through cooling towers and use of evaporative condensers in the refrigeration system. Either of these methods greatly reduces the net water requirements, to 10 per cent or less of the gross water requirements of other systems. The only water loss is that which evaporates or drifts off as spray, and the amount of make-up water may be only 2 to 5 per cent. These methods are especially suited to installations where the cost of condensing water used only once would be prohibitive, where the amount of water available is limited, and where there is a problem of disposal of large quantities of condensing water.

PREVENTION OF POLLUTION

Most natural ground water is bacteriologically pure, but it can become polluted through contact with chemical and organic impurities. (The term pollution, in this report, refers to the sanitary or bacterial condition of the water.)

Chemical contamination is a matter of degree, in most cases, depending on the use to which the water is to be put. For example, water containing 1,500 parts per million (ppm) of chloride is not satisfactory for domestic use, but it may be usable for other purposes.

The ground water in the Pittsburgh area is mostly free of bacterial pollution and objectionable chemical contamination, although derived principally from highly polluted sources. The filtering action of the river-bed sediments and of the aquifer itself, maintains the bacterial purity of the influent ground water. However, certain chemical contaminants cannot be filtered out and may ruin a good supply if their concentration is gradually built up. The state of the original source of supply, then, is highly important. In the highly industrialized Pittsburgh area, the great wonder is that the ground water remains relatively uncontaminated. Although efforts are being made to clean up the streams, the threat of contamination remains. As recently as the summer of 1948 there was a problem of taste and odor in some surface and some ground-water supplies during a period of low stream flow. Coincident with this river condition, however, must have been the inflow of unusually large quantities of industrial wastes, possibly phenols. It has been reported that an industry in nearby Beaver County has contaminated its own ground-water supply by discharging chemical wastes near the wells.

Thus, the prevention of pollution is a major method of conserving the existing ground-water supplies for beneficial use.

ARTIFICIAL RECHARGE

Water is a priceless natural resource, which, unlike most natural resources, is replenished by nature. The supply is not inexhaustible, how-

ever, and conservation of water can be practiced in many ways. A method that is coming into practical use in ground-water supply is that of artificially recharging the underground reservoirs. Notable examples of artificial recharge are in southern California (Mitchelson and Muckel, 1937), on western Long Island (Brashears, 1946), at Dayton, Ohio (Norris, 1948), and at Louisville, Ky. (Guyton, 1946). Among the devices used are spreading basins which allow surface water to seep into the ground, infiltration trenches which drain water from a surface source and convey it to underground storage, and recharge wells through which new or used water is added directly to the aquifer. The first two devices usually cannot be employed in built-up areas, but recharge wells can be used anywhere that the underground hydraulic, geologic, and economic conditions permit. In general, if ground water can be extracted, it can be replaced. Two business areas in which recharge wells are used are Brooklyn, N. Y., and Canton, Ohio.

The Triangle area of Pittsburgh appears to be geologically suitable for the operation of recharge wells. A localized year-round cone of depression is available for the retention of water returned by this method to the aquifer, so that there would be little or no loss of the recharged water. The procedure would be essentially as follows: Wells would be drilled for recharge, similar in construction to the producing wells, at the most favorable sites; pure water from the municipal supply or used air-conditioning water would be introduced at appropriate times; the water level would rise as storage increased or would remain essentially constant if total recharge was equal to total pumping; natural infiltration from the rivers would continue at rates depending on the position of the new or stabilized water table. In this way pumping lifts would be reduced, the regional cone of depression would be reduced, and more ground water would be available, for everyone's use.

At least four major considerations would be involved in any plan of artificial recharge in the Triangle area:

1. The availability of recharge water, in the desired amount and suitable in both quality and temperature.
2. The necessity of a coordinated plan by which users would benefit in proportion to their contributions.
3. The necessity of a program for determining the effectiveness of the recharge.
4. Economic factors, varying among the many well owners.

A discussion of these four points will indicate the nature and scope of artificial recharge as a means of maintaining the yield of the aquifer:

1. The correct amount of recharge water to be applied at any time probably could be determined on the basis of water-level and other data in the area. The water necessarily would have to be relatively pure and to contain no suspended matter, because recharge wells become clogged quickly by sediments in the return-water supply. In general, air-conditioning water meets this qualification. In order to maintain or improve the temperature condition of the natural ground water, the recharge

water preferably should not be warmer than 60°. This qualification eliminates the use of municipal water during the period from about May through September (see fig. 3). This is significant because it is this period in which recharge would do the most good, while water levels are declining and temperatures are increasing. The use of available air-conditioning discharge water would partly satisfy the quantity requirement but would fail to meet the temperature requirement after about July (on the basis of fig. 3).

2. With the great number of individual users of ground water in the Triangle area, each well affects adjacent wells, and in almost every case artificial recharge by one would benefit surrounding users. Thus, an equitable recharge program should include all the major producers. Each should return water to the aquifer in proportion to the amount withdrawn. Such a plan would require a carefully drawn and administered agreement among the participants.

3. The effectiveness of artificial recharge by means of return wells could be measured by a program of water-level observations similar to the present Federal-State program but of somewhat fuller scope. Additional observation wells, some equipped with automatic water-stage recorders, would be needed in some parts of the area. Just such an "accounting system" is in operation in the Brooklyn area on Long Island.

4. The value to each well owner of a program of artificial recharge would determine the extent of his individual participation. The cost factor is primary, and its evaluation would prove difficult, considering the many incidental factors involved. However, some agreement would be necessary between participants and nonparticipants. A well owner probably could not be prevented from pumping ground water because he did not or could not engage in the recharging program.

MAINTENANCE OF AN INVENTORY

In any business a system of accounting is necessary to insure the proper and profitable conduct of affairs. The business of ground-water supply is no exception, and an important part of its accounting method is the systematic inventory of supply and demand. The supply is measured by the observation of water-level fluctuations in the storage reservoir and the determination of sources and rates of recharge. The demand is measured by periodic or continuous surveys of pumpage. Any system of legal control would necessarily be based on adequate knowledge of the factors affecting the supply and demand of ground water.

It is obvious, therefore, that the inventory now being made and reported in the Pittsburgh area will be one of the foundations of any future legal action. It follows that the entire accounting system should be maintained until and during such time as controls are effective. The results of the continuing inventory in Pittsburgh are made available to the public through State and Federal publications. The State reports are the W-series Bulletins, and the Federal reports are the annual water-supply papers of the Geological Survey. Both types of reports are available in offices of the cooperating agencies and in many public libraries.

SUMMARY AND CONCLUSIONS

This report has presented the many aspects of ground water in the Triangle area of Pittsburgh, mainly from the point of view of a specialized use of this natural resource—air conditioning. The water requirements for comfort air conditioning have been shown to be reasonable in comparison with the available supply, at least under present conditions. These present conditions of the supply have been illustrated with basic data covering a 21-year period of pumping. The steady increase in ground-water use for air conditioning has resulted from a growing awareness of the value of ground water for this specific purpose. The trend appears to be that pumping will become heavier in the Triangle area and in Pittsburgh in general. Limitations of a large-scale increase stem from relatively small storage and drawdown potential of the aquifer in the Triangle area, the reduction of natural river recharge, the possible increase in water temperature, and possible legal control of drilling and pumping.

The future of the Triangle area as an area of ground-water development is promising, but certain proposed changes in conditions probably would reduce the net dependable yield of closely spaced wells. The advantages and disadvantages of artificial recharge have been outlined. Voluntary control of pumping, including individual reduction of waste, may prove to be the easiest and best method of conserving the supply and minimizing the necessity for legal control.

Some additional air-conditioning units using ground water can be installed in the area. Small systems requiring less than 100 gallons a minute of water would add less than 7 million gallons a year each to the seasonal load. Efficient air-conditioning systems for small business establishments are available in the industry, and they could operate on 30 to 40 gallons a minute with no reuse of water. During an average season each such unit would use about 2,300,000 gallons of water, or only 0.1 per cent of the total amount used in 1950. In view of occasional abandonment of large wells, many smaller ground-water withdrawals can be made throughout most of the area.

The installation of air-conditioning systems using ground water should be based on all available ground-water data and should utilize the combined services of qualified engineers, well drillers, and equipment manufacturers.

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INDEX

P 1747 (6)